# The Effect of Dyadic Interactions on Learning Rotate Gesture for Technology-Naïve Older Adults

**Martin Mihajlov**
Ss. Cyril and Methodius University
Goce Delcev 9b
1000 Skopje, Macedonia
martin@eccf.ukim.edu.mk

**Effie Lai-Chong Law**
University of Leicester
University Road
Leicester LE1 7RH, UK
lcl9@leicester.ac.uk

**Mark Springett**
Middlesex University
The Burroughs
London NW4 4BT, UK
m.springett@mdx.ac.uk

**ABSTRACT**

Older adults having limited experience with modern computing technology may find it difficult to learn touch gestures, especially the more complex rotate gesture. Social interactions, as implied by social constructivism, are assumed to be powerful in enabling older adults to acquire the skill of touch gestures. The social effect can be reinforced with the motivational effect of digital games. To verify the assumption, we conducted empirical studies with 59 older adults, who were divided into two groups: 17 Singles and 21 Dyads. They were asked to play a set of digital games on a multi-touch tabletop. Results show that on average Dyads have spent significantly longer time in the games and have performed a significantly higher number of correct rotate gestures than Singles. Future work focuses on analyzing the emotional aspect of social interactions and identifying further applications of social gaming to other ageing issues.

**Keywords**

Older adult; Social interaction; Game; Touch; Rotate;

## INTRODUCTION

Demographic aging is a worldwide phenomenon [46]. In Europe alone, 17% of the population is older than 65 years, estimated to increase to 30% by 2060 [6]. Consequently, it would be reasonable to expect that the increase in the number of older adults aged 65+ would lead to the corresponding increase in the percentage of technology use for this age-bracket among the population of Europe. Nevertheless, the usage rate has remained low with 16% of people aged 60 using mobile devices for activities beyond their calling features [23]. Barnard and colleagues [4] remarked that people who do not work with computers in their jobs have difficulty in engaging with digital products and are thus susceptible to digital exclusion. Furthermore, the lack of previous experience and the concomitant need of support, which may not be available or accessible, tend to hinder older adults from enjoying and appreciating the benefits of interacting with technology [4][25]. In contrast, younger generations, who normally use computers at school or at work, are enabled to engage with new technologies.

The anxiety of older adults towards technology use is highly related to the design of the system and its interaction methods [4]. Usability evaluation studies of classical input devices for older adults have revealed a multitude of issues [45][58]. Mouse manipulation requires high hand-eye coordination, which is affected by the decline in cognitive skills [55]. Most mouse actions require precise hand movements, which are affected by age-related changes in motor skills [14]. Keyboard entry is quickly affected by fatigue and discomfort in the forearm and hands [41]. These and other noted difficulties of external input devices have greatly influenced people's attitudes towards computers. With the emergence of touch-screen devices the direct contact with the display screen has removed the need of intermediary devices for interaction, thus decreasing the apparent apprehension of use [31] [54].

The benefits and drawbacks of multi-touch surfaces for older adults are relevant to understanding the aging process. The most notable implication of aging is the change in a person's physical and motor abilities. The movements of older adults are generally slower, with an increased difficulty with fine motor activity and coordination [15]. A large touch-based surface is physically demanding to interact with, especially for older adults. The exertion required may undermine the quality of the interaction process [16]. Another common issue of aging is loss of or impaired vision. This can be addressed by the facility of a multi-touch surface supporting enlargement of visual information to a large scale [18]. Finally, the decline in memory associated with aging changes the short-term maintenance and manipulation of information in working memory [12]. This implies that interactions with touch-based interfaces need to be easy and quick in order for them to be learnable.

Mertens and colleagues [32] showed that interacting with new technologies and learning a new interaction technique can be a demanding task for older adults. To overcome this problem, playing simple games on a touch-based tabletop has been suggested as a promising approach for alleviating the reluctance and fear of using digital devices [33]. Apart from their motivational power, digital games have the


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potential to address an important issue facing older adults – isolation – when games are played in a social context (e.g., [1]). Considering that touch-based devices are available in a broad range of sizes, their social affordance is implied from their form factor [51]. For example, a mobile device is usable for one user at a time, while an interactive multi-touch tabletop supports simultaneous interactions from several users. Besides the social affordance, the use of larger devices for older adults is an advantageous form factor as executing touch gestures on small devices demands high dexterity of users [56]. With the insights gained from the above reviews, we have proposed the following assumption:

*Given simple digital games on an interactive tabletop, older adults are enabled to learn touch-based gestures and can learn the gestures more effectively and efficiently when playing the games in dyad than individually*.

To verify the assumption, we have devised and conducted empirical studies accordingly: having pairs of older adults play a set of simple digital games on a multi-touch tabletop. The main touch gestures to be learned through the games are DRAG and ROTATE. While DRAG is basic and easy to learn, ROTATE is relatively more advanced and challenging to master (e.g., [22]). Our analysis of DRAG verified the above assumption that older adults could learn DRAG better in dyad than individually (under preparation). In this paper, we explore whether the same verification would be held for the more complex touch gesture of ROTATE

In the following sections we first present reviews on the related work. Next, we describe the research methods and the design of a digital game that is aimed to facilitate the learning of ROTATE. In the section Results, we compare the data between the two groups –Singles and Dyads - and build regression model of the learning process. The implications from the empirical results are then discussed before we conclude with our future work.

## RELATED WORK

In this section, we present reviews of the related work on two major topics: touch-based interaction and social interactions. Relevant theoretical frameworks and empirical studies are examined to lay the cornerstones of our work.

### Touch-based Interaction

Research on touch-based interaction and older adults is mostly focused on advantages and disadvantages of this interaction modality for elderly users. A common evaluation approach is to compare older adults' performance in completing tasks using touch-based gestures with their younger counterparts'. These studies revealed that age could significantly affect task performance. Typically, older adults needed more time to complete the given tasks [10] and were also prone to make more errors than younger participants [26]. In addition, task performance can be affected by manual dexterity [27], visual impairment [30] and cognitive effort [53].

Previous experience with technology has been used as a factor to include or exclude older participants in or from studies (e.g., [21] [48]), but the differences in touch-based interaction performance between novice and experienced users have rarely been studied. Some studies show that previous technological experience and cognitive capabilities, as compared with age, are stronger predictors of older adults' performance in interacting with new technologies (e.g., [11]) and that the learning needs of older adults should be taken into consideration when evaluating their acceptance of touch-based interaction (e.g., [9]).

Other studies compared interaction performances between different screen sizes (e.g., [24]), screen orientations (e.g., [35]) or positions (e.g., [40]) to evaluate how the layout of the content and the way users holding devices influenced their interaction methods. Interestingly, older adults with low manual dexterity had no significant problems while interacting with large horizontal touchscreens [2]. Additionally, Kobayashi and colleagues [28] reported on the increased performance of older adults when using tablets over devices with smaller screen sizes, despite the increased distances required for executing the gestures.

Overall, results of the studies on specific characteristics of the elderly population confirm the importance of usability, accessibility and ergonomics for enabling this target group to adopt new technologies [59].

### Social interactions

The theoretical assumption that social interactions are central for learning is firmly grounded in social constructivism; a philosophical framework mostly found upon the ideas of two great scholars - Vygotsky and Dewey [36]. Among others, two key ideas they shared are: the significant contribution of social interactions and tool-mediated (especially languages) activities to the development of knowledge and skills; the crucial role of communicative dialogue in the formation of mutual intelligibility. In particular, Vygotsky's notion of Zone of Proximal Development (ZPD) [34] is widely espoused by many contemporary researchers for adult learning (e.g., [43]).

The tenet of socially shared cognition [42] is that learning is a process of knowledge construction, which is inherently social in nature. People build their knowledge structures on the basis of what they are told by others, orally, in writing, in pictures, and in gestures [42]. Furthermore, social experience can shape the kinds of interpretative processes available to individuals. Constructivism makes cognition integral to social processes. In the context of our study, playing digital games collaboratively is a tool-mediated social learning activity that is fostered through dialogues and body gestures.

While the earlier work of socially shared cognition is mostly on children, more recent studies have shown that the framework is applicable to older adults. For instance, Stine-Morrow and colleagues [47] demonstrate that cognitive performance in older adults is enhanced when they engage in collaborative problem-solving. Social learning can also improve performance in patients suffering from memory deficiencies (e.g., [7] [19] [49]).

Interestingly, some studies have identified a counterintuitive phenomenon called collaborative inhibition, which occurs when individuals in a social setting do not contribute as much information as they would when working individually [44]. This phenomenon is more prevalent when the participants are randomly paired as opposed to being paired with familiar partners [39]. Nevertheless, inhibited information can be recovered over time and collaborative costs do not seem to be long-lasting [7].

New technologies utilize the proved effect of social interactions to encourage older adults to use them [8][13][29]. One good example is Sharetouch [52], which is a multi-touch tabletop serving as a coffee table; older adults find the interaction with the device more stimulating than using it alone. Nonetheless, we argue that benefits of social interactions for older adults' learning can be reinforced with games [57].

## METHODS

In this section we describe the methodological approaches used in our study.

### Participants & Equipment

To observe the largest possible extent of learning of touch-based gestures, we recruited participants having no experience with the interface under evaluation. Through a retirement community in Macedonia, we recruited 59 participants (24 male and 35 female) with an average age of 67.32 years. All participants had minimal experience of interacting with modern computing technologies. Their technological experiences were mostly limited to making calls on a keypad-based mobile phone without any interaction with a computer-based device and/or features. The participants were in relatively good health with some negligible complaints on the occurrence of a slight discomfort when they actively used their extremities.

For equipment we used a 27.5" multi-touch interactive learning tabletop from Smart Technologies (SMART Table 230i®). This tabletop supports simultaneous interactions of multiple users with the same interface, as the device registers up to 80 simultaneous gestures. The recording of the experiment sessions was performed with a Canon Vixia HF R20 camcorder.

### Experiment Design

For the purpose of this study, we used a game called PUZZLE (Figure 1) particularly suitable for applying the ROTATE gesture. As the initial status of PUZZLE, a brown square made of jigsaw pieces is in the centre of the tabletop surface, partially overlapping with the white non-movable pattern underneath, which is built up with different shapes. Players should dislodge individual jigsaw pieces, match them with the corresponding shapes of the white pattern and then place them onto the appropriate locations. Visual feedback in terms of colour change from red to green is given when a jigsaw piece is correctly placed. It is necessary for the players to rotate the jigsaw pieces to fit into the shapes of the white pattern.

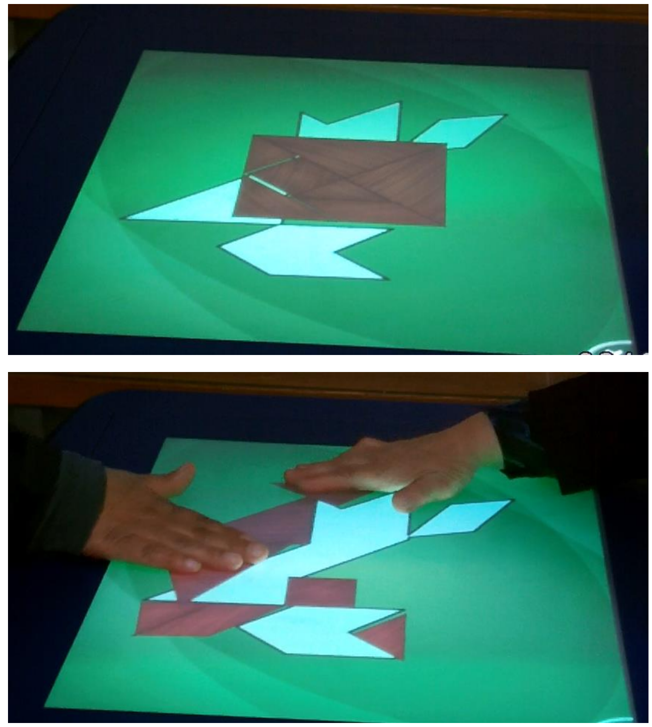

**Figure 1. The tabletop game PUZZLE. The upper image shows the initial status of the game. The lower image shows the dislodged brown jigsaw pieces, which both players attempt to place onto the white pattern with touch gestures**

To evaluate how collaborative gameplay can encourage interactions with touch-based technologies as well as enhance the acquisition of proper touch gestures, the participants were divided into two groups: Singles (17 participants) and Dyads (42 participants). In the Singles group, individual participants played the games on their own, whereas in the Dyads group two participants played the games as a team. All the participants in the Dyads group were mixed-gender except for a single case where both participants were female.

Over two days, 17 Singles and 21 Dyads evaluation sessions were conducted in a special room with the experiment setup. Each session consisted of two parts and lasted approximately 10 minutes. In the first part every participant filled out a short demographic questionnaire about their technology usage and personal health whereas in the second part the participants were asked to play the game. The gameplay of the sessions was videotaped, resulting in almost 6 hours of videos. As the main goal of the study was to understand how technology-naïve people acquired different touch gestures, no instruction or demonstration how to play the game was provided. At the beginning of a session, the participants were told that they were going to play with a new device in order to improve their isolation from technology. Two researchers were present throughout all these sessions, playing the roles of administrator and observer.

In order to prepare the data for analysis, all of the recorded videos were transcribed and time-stamped. The audiovisual data was coded into variables in parallel by two independent parties, whereas all discrepancies in the coded data were resolved by a joint recode. The main purpose of coding scheme was to identify gesture types and durations, and was applied in accordance with the definitions specified in the sub-section Variables.

### Game Design

In the game PUZZLE, the initial screen presents eight jigsaw pieces with different shapes coalesced as a square in the centre of the screen (Figure 1). The goal of the game is to move and rotate each jigsaw piece to fit into a target location with the corresponding shape. In order to complete the game the participant had to perform two different gestures - DRAG and ROTATE. As mentioned earlier, we have developed a set of digital games for evaluating the learnability of touch gestures. Prior to PUZZLE, the participants played a game for which DRAG was the main gesture required; dragging a label with a country name to a location of a world map on the tabletop (Figure 2). The participants demonstrated that they had acquired DRAG [33].

#### *Variables*

To analyze the data we separate the interactions with the jigsaw pieces into units of analysis - trials. A trial is a series of actions beginning from the moment a player starts interacting with a jigsaw piece until the interaction stops and the player begins interacting with another piece. If the player revisits the same jigsaw piece later in the game, the series of interactions are counted as a new trial. For each trial we measure the following variables:

- **Gesture Type:** Types of (in)correct gesture performed.
- **Number of gestures:** Number of each gesture type per trial.
- **Trial time:** Duration of the interaction with a jigsaw piece.

In the analysis of the videos, we observed that participants make 4 distinct rotational gestures during gameplay. We classified each of these gesture types as correct or incorrect based on whether the gesture initiated a rotational movement during the interaction with a jigsaw piece.

- **rotate-f** - A correct rotational gesture where the participant uses two or more disjointed fingers of the same hand.
- r**otate-h** - A correct rotational gesture where the participant uses two or more fingers from both hands.
- **s-rotate** - An incorrect rotational gesture where the participant uses only a single finger from one hand.
- **w-rotate** - An incorrect rotational gesture where the participant uses two or more fingers joined together and essentially tries to rotate with the wrist.

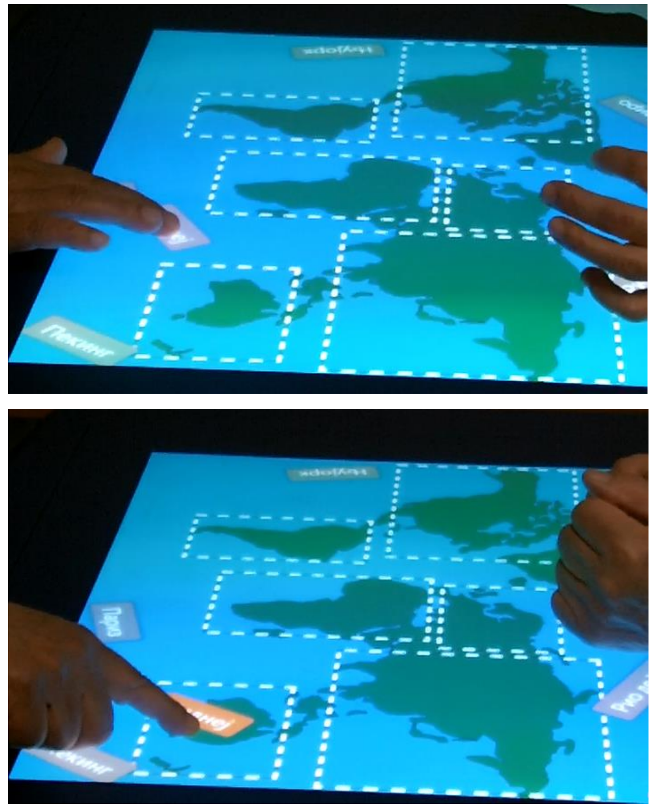

**Figure 2. The tabletop game Hotspot. The upper image shows the initial status of the game with the grey labels of capital cities scattered on the tabletop screen. The lower image shows the result of a player's successful DRAG, the colour of the label is changed from grey to orange as visual feedback.**

### Research Questions and Hypothesis

To achieve the goal of the game PUZZLE, participants are required to perform different rotate gestures. When the system does not respond to a performed ROTATE in an expected manner, the gesture is considered incorrect, and alternatively, when the system responds to a performed ROTATE, the gesture is considered as correct. We want to evaluate whether the participants can learn the correct rotate gesture as they progress in playing the game. We also want to compare the rotate gesture patterns of the Singles players with those of the Dyads players to evaluate whether collaborative playing improves gesture learning. We have formulated the following hypotheses:

***H1****: Collaborative playing induces higher game involvement in terms of a significantly longer playing time and a significantly higher number of gestures and interactions for the Dyads players than for Singles players.*

***H2****: Learning ROTATE through the game can be evident by having a significantly higher number of correct gestures and a significantly lower number of incorrect gestures at the end of the game than in the beginning of the game.*

***H3****: There is a significant difference in the extent of improvement in gesture learning behavior between the Singles players and the Dyads players.*

## RESULTS

The Singles group started with 17 participants. However, two of them had no interactions with the tabletop at all, we collected and evaluated data from only 15 participants. On average, the participants performed a total of 16.73 interactions (SD=6.87), with 7.6 interactions (SD=4.32) being rotational gestures. They played the game for 124.87 seconds (SD=62.53), needing 10.2 seconds (SD=8.39) to initiate the first rotate gesture and 71.2 seconds (SD=60.35) to make the first correct rotational gesture. In the Dyads group, all 42 participants (21 couples) engaged with the game. On average they performed 34.95 interactions (SD=19.19) of which 15.33 (SD=7.25) were interactions with rotational gestures. They played the game for 253.9 seconds (SD=123.48), initiating the first rotational gesture in 14.05 seconds (SD=13.24) and the first correct rotational gesture in 74.81 seconds (SD=71.87). The detailed results are presented in Table 1.

| Variable | Singles | | Dyads | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| **Rotation interactions** | 7.60 | 4.32 | 15.33 | 7.25 |
| **rotate-f** | 3.67 | 7.51 | 7.10 | 8.79 |
| **rotate-h** | 3.93 | 11.54 | 12.43 | 19.87 |
| **s-rotate** | 4.73 | 5.47 | 19.57 | 24.97 |
| **w-rotate** | 21.13 | 17.25 | 29.19 | 22.32 |
| **Rotation time** | 90.60 | 55.12 | 179.76 | 83.99 |
| **Total number of interactions** | 16.73 | 6.87 | 34.95 | 19.19 |
| **Total Time** | 124.87 | 62.53 | 253.90 | 123.48 |
| **First rotation** | 10.20 | 8.39 | 14.05 | 13.24 |
| **First correct rotation** | 71.20 | 60.35 | 74.81 | 71.87 |

**Table 1. Descriptive statistics for the participants playing the game PUZZLE**

The Kolmogorov-Smirnov test revealed non-normal distribution of data for most of the measured variables, while the Levene's test showed no significant difference for the homogeneity of variance. Therefore, as the assumption of normal distribution was violated, to evaluate the behavior of single and dyad groups, we used the Mann-Whitney non-parametric test to compare the recorded variables between the groups. The results of the test are presented in Table 2.

| Variable | U | Z | Sig. |
|---|---|---|---|
| **Rotation Interactions** | 54.00 | -3.329 | 0.001 |
| **rotate-f** | 97.00 | -1.956 | 0.051 |
| **rotate-h gesture** | 93.50 | -2.136 | 0.032 |
| **s-rotate** | 86.50 | -2.387 | 0.016 |
| **w-rotate** | 125.50 | -1.028 | 0.312 |
| **Rotation time** | 55.50 | -3.274 | 0.001 |
| **Total no. of interactions** | 50.50 | -3.438 | 0.000 |
| **Total time** | 47.00 | -3.547 | 0.000 |
| **First rotation** | 138.00 | -0.635 | 0.535 |
| **First correct rotation** | 147.00 | -0.337 | 0.745 |

**Table 2. Mann-Whitney test for differences between the Singles and Dyads participants**

The results of the Mann-Whitney tests reveal significant differences for both time-related variables and gestures. The Dyads participants spent significantly more time playing the game PUZZLE (U=47.00, Z=-3.547, $p$=0.00), and devoted significantly more time to performing the rotate gestures (U=55.00, Z=-3.274, $p$=0.001). These findings are in support of the hypothesis H1. There are no significant differences for the time before a participant makes the first rotate gesture, and for the time before a participant makes the first correct rotate gesture.

There is a significant difference between the Singles and Dyads participants for the total number of interactions (U=55.50, Z=-3.438, $p$=0.00). Consequently, the Dyads participants use significantly more rotate interactions than single participants (U=54.00, Z=-3.329, $p$=0.001); the results also support hypothesis H1.

Analyzing each gesture separately, with regard to correct gestures, the Singles participants performed rotate-f (U=93.50, Z=-2.136, $p$=0.032) and rotate-h (U=86.50, Z=-2.387, p=0.016) gestures per interaction significantly less than the Dyads participants did. With regard to incorrect gestures, the Singles participants use s-rotate (U=97.00, Z=-1.956, p=0.048) significantly less than the Dyads participants do, whereas there is no statistical significance for w-rotate (U=125.50, Z=-1.028, p=0.312) between the two groups. These results partially support hypothesis H2, and support hypothesis H3.

To analyze the types of rotate gestures used in each interaction, we normalized the value for the number of gestures (Gr) based on the total number of gestures in the interaction (Gtotal). The new value (gr=Gr/Gtotal) was separately calculated for the 4 different types of rotate gestures. The results show that in each interaction the Singles participants used the correct gestures, rotate-f (U=98.00, Z=-1.982, p=0.049) and rotate-h (U=96.00, Z=-2.066, p=0.039), significantly less than the Dyads participants did. Conversely, the Singles participants used the incorrect gesture w-rotate more often than the Dyads participants did (U=92.00, Z=-2.104, p=0.036), while there is no significant difference for s-rotate (U=120.50, Z=-1.194, p=0.239). These results support hypothesis H3.

| Model | R | R2 | Adjusted R2 | Std. Error | Sum of Squares | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|---|
| *s-rotate* | 0.038 | 0.001 | -0.017 | 1.5843 | 0.402 | 0.201 | 0.08 | 0.923 |
| *w-rotate* | 0.071 | 0.005 | -0.013 | 3.2025 | 5.629 | 2.814 | 0.274 | 0.761 |
| *rotate-f* | 0.174 | 0.03 | 0.013 | 1.8386 | 11.533 | 5.767 | 1.706 | 0.186 |
| *rotate-h* | 0.071 | 0.005 | -0.013 | 1.7405 | 1.676 | 0.838 | 0.277 | 0.759 |

**Table 3. Multiple regression results for the Singles group**

| Model | R | R2 | Adjusted R2 | Std. Error | Sum of Squares | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|---|
| *s-rotate* | 0.075 | 0.006 | -0.001 | 2.4696 | 10.766 | 5.383 | 0.883 | 0.415 |
| *w-rotate* | 0.039 | 0.002 | -0.005 | 2.9096 | 4.044 | 2.022 | 0.239 | 0.788 |
| *rotate-f* | 0.144 | 0.021 | 0.014 | 1.1781 | 9.109 | 4.554 | 3.281 | 0.039 |
| *rotate-h* | 0.194 | 0.038 | 0.031 | 2.3042 | 64.754 | 32.377 | 6.098 | 0.003 |

**Table 4. Multiple regression results for the Dyads group**

| | rotate-f | | | | | rotate-h | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | B | Std. Error | Beta | t | Sig. | B | Std. Error | Beta | t | Sig. |
| *Beginning* | 0.547 | 0.114 | | 4.782 | 0 | 0.179 | 0.224 | | 0.801 | 0.424 |
| *Middle* | 0.059 | 0.163 | 0.023 | 0.36 | 0.719 | 0.955 | 0.318 | 0.192 | 3.004 | 0.003 |
| *End* | -0.328 | 0.162 | -0.131 | -2.023 | 0.044 | 0.964 | 0.317 | 0.194 | 3.037 | 0.003 |

## Modeling Learning Behaviour

To discover the learning behaviour of the participants, it is necessary to observe how the use of each type of rotate gesture changes over time. Hence, for every group we divided the data from each playing session into three equal segments: beginning, middle, and end. In order to build a gestural learning model for each participant we proceeded with multiple regression analysis where each segment was treated as a categorical predictor. We used the beginning segment as a baseline and compared its value with the middle and end segments.

To build general behaviour models for the Singles and the Dyads participants, we combined the data of the respective groups. Results of the multiple regression analyses are presented in Tables 3 and Table 4. Accordingly, the Singles group show no significant difference of variance and no correlation between the gestures whereas the Dyads group show a significant difference for the rotate-f ($F_{(2,312)}$=3.281, $p$=0.039), and rotate-h ($F_{(2,312)}$=6.098, $p$=0.003) gestures.

In the further analysis of the coefficients for the categorical predictors, there is evidence for a significant decrease in the use of the rotate gesture between the beginning of the game and the end of the game. In contrast, there are significant increases in the use of the rotate-h gesture between the beginning and the middle of the game and between the beginning and the end of the game. Detailed results for each gesture are presented in Table 5.

The most representative statistically significant models inferred from the multiple regression analysis are consistent with the playing patterns observed, which can be divided into three categories:

- **Non-progressive playing**. The participant plays the game by continuously using a wrong rotate gesture.
- **Active learning**. The participant begins playing the game with a wrong rotate gesture and over time starts using a correct rotate gesture.
- **Active unlearning**. The participant begins playing the game with a correct rotate gesture and over time starts using an incorrect rotate gesture.

For the Singles group, the non-progressive playing model is predominant. Except for one active learning participant, all Singles participants followed this playing pattern, with an intense focus on using w-rotate. There were some occurrences of s-rotate, which usually diminished over time. The use of the correct gestures was very low as these gestures were not even attempted by more than half of the Singles participants. This essentially shows that there is no learning of the correct rotate gestures in the Singles group. This is in support of the alternate hypothesis for H2.

During the sessions of the Dyads groups, all the three patterns were observed. Ten participants can be classified as Active Learners, with rotate-h receiving the highest focus towards the end of the game. Seven participants belong in the Active Unlearners category with w-rotate being their gesture of choice. Finally, three participants' behaviours match with the Non-progressive Playing pattern with w-rotate gesture receiving their greatest attention.

## DISCUSSION

In this section, we look further into three issues: some plausible reasons for the better performance of social players (the Dyads group) as opposed to sole players (the Singles Group); the complexity of a specific type of rotate gesture; the emotional impact of social gameplay.

### Single vs. social players

The implication of the first hypothesis H1 is straight-forward: when playing together participants tend to play more. They spend more time on the game and make more interactions and gestures, and, as shown by the other hypotheses, leading to more effective learning of touch gestures. The second hypothesis is partially confirmed as the Singles participants exhibit learning behaviours only to a small extent while the Dyads participants demonstrate learning behaviours to a larger extent. A plausible explanation is that as the Single participants play the game less and have no social support in the discovery process, they tend to give up on the game more quickly and are never engaged in a learning process, reducing the exploration time during which they could have gained better understanding of the rotate gestures. One finding that is not reported in the above results, but has been observed in the videos is that the game completion rate is notably higher for the Dyads participants.

The general models imply that the Singles participants are non-progressive players whereas the Dyads participants are active learners. This distinct contrast is highly consistent with the theoretical frameworks of social constructivism, as mentioned in Related Work. It is plausible that the collaborative effort enables the Dyads participants to co-develop effective gameplay strategies to fulfill the goal of the game while exploring the use of the touch gestures. Furthermore, the fun of exploring the game together could be attributed as a key factor to sustain the Dyads participants' effort, despite the frustration they had experienced caused by unsuccessful attempts to resolve the challenge. In addition, the notion of Zone of Proximal Development (ZPD) [34] can explain the observation that abler and more confident players provide scaffold to their weaker counterparts, who with the given "boost" were enabled to pick up the gesture much quicker than struggling on their own.

The confirmations of H1 and H3 verify the motivational effect of collaborative gameplay, as the players in the Dyads group showed a stronger tendency than their counterparts in the Singles group to sustain the rather cognitively as well as physically demanding interactions with the jigsaw pieces of PUZZLE.

### Complexity of w-rotate

From all the findings in this study, the results for the w-rotate gesture seem slightly peculiar. To interpret these findings it is necessary to understand the complexity of this gesture. The performance of w-rotate contains silent rotation affordances for which the participants lack awareness. Specifically, while using joined fingers to perform the w-rotate gesture during the rotation of the wrist, the participant might unconsciously separate the fingers and induce a miniscule rotate. Although time-consuming and less-rewarding as the gesture did not help the participants make a good progress of the game, some participants continued to perform this gesture until the accidental gesture change was induced multiple times. This led to a false impression that the performed gesture was correct, and that the system was ineffective as it could not infer the intention of the participants.

### Emotional gain of social gaming

This paper focuses on the effect of the collaborative gameplay on the cognitive gain in terms of the learning of the rotate gestures. Nonetheless, we are aware that the emotional gain from social gaming is equally, if not more, important. The motivational power of games works not only for young people, as documented in a vast body of literature, but apparently also for their older counterparts [43]. However, we have not formally evaluated the emotional aspect of the gameplay by, for instance, asking participants to self-report their emotional responses. It is because we avoid overwhelming the participants with an additional measurement procedure as they have already been presented new challenges to deal with unfamiliar technologies. Nonetheless, we have captured their dialogues, facial expressions and bodily gestures that have naturally happened during the gameplay. While analysis of such qualitative data, which is a resource-demanding process, has been planned, it is yet to be realized as our future work. Specifically, we have already identified a promising theoretical framework – Activity Theory [20] – to understand the complexity of the interactions.

## CONCLUSION

While our study is not the first attempt to utilize the potential of social interaction and digital game to address the issues related to ageing, it shows that the approach has been effective for technology-naïve older adults, unlike most of the earlier studies where older participants were more technologically experienced. The confirmed positive effect of social gaming for old adults to learn the rather complex touch-gesture has significant implications. The finding is encouraging as technology anxiety can be overcome in a social gaming setting. In our future work, we aim to deepen our understanding of the emotional aspect of social gaming, especially which game elements are particularly effective in engaging and motivating older adults to interact.

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